Plan-Aware Behavioral Modeling

M. Lease, Intel Research Seattle

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Matthew Lease
Intel Research Seattle
mlease@intel-research.net

ABSTRACT
One exciting promise of ubiquitous computing is that increased fidelity in natural world sensing will enable computers to better serve people via responsive or anticipatory behavior. We believe better behavioral modeling of users can play an important role in helping to make this possible. We propose the technique of plan-aware behavioral modeling to reason about deviations between a user's intended plan of behavior and behavior actually observed. We have been investigating this general technique in the context of supporting an everyday activity: musical performance. Preliminary evaluation suggests the technique has potential meriting further investigation.

Keywords
Behavior modeling, Bayesian network, proactivity

INTRODUCTION

One exciting promise of ubiquitous computing is that increased fidelity in natural world sensing will enable computers to better serve people via responsive or anticipatory behavior. We believe better behavioral modeling of users can play an important role in making this possible. Continuing improvements in sensing technologies provide increasing opportunities for computers to monitor user behavior more accurately and in new ways. By analyzing the data collected from this monitoring, user behavior may be modeled abstractly to derive numerous insights. For example, when a user performs a certain action, a computer could consult that user's behavioral model to reason about what caused the user behave in this manner (i.e. diagnosis). Such a model could also be used to better predict a user's future actions, enabling the computer to provide proactive assistance appropriate to the user's expected behavior. Finally, such models can be studied to improve our own understanding of human behavior.

We have been exploring behavioral modeling for situations in which a computer knows a user is trying to perform a given task and can monitor the user's progress towards completing the task. To be more specific, the user has a plan of successive steps he intends to perform, but he may deviate from this plan by accident due to limitations in human accuracy. We believe there are many interesting scenarios in which this specific situation arises. Our goal is to enable ubiquitous assistance in these scenarios to improve user accuracy in carrying out the intended plan.

To provide a real-world example of such a scenario, consider the situation of in-vehicle route planning assistance [1]. In this scenario, a driver asks his car's telematics system for driving directions to a given destination address. The system is able to determine the car's current location via GPS and uses this information to plot an appropriate route. Furthermore, the system may also offer real-time monitoring of the vehicle's progress towards the specified destination, automatically updating its directions whenever the driver makes a wrong turn, etc. While such automated route re-planning is obviously a valuable feature, the driver would probably prefer to have not made the wrong turn at all. We believe existing telematics systems could be extended with plan-aware behavioral modeling to help make this possible. By real-time monitoring of such mistakes and recognizing patterns of their occurrence, the system may be able to predict such an upcoming wrong turn and proactively tailor interaction with the driver, providing him with sufficient assistance to prevent the mistake's occurrence.

SUPPORTING MUSICAL PERFORMANCE

We have been investigating the application of plan-aware behavioral modeling to providing ubiquitous assistance for musical performance. We chose this application because it provided us with an existing, everyday activity to support within a novel environment for evaluating ubiquitous computing techniques. In this application, the user is a musician and the plan of behavior is represented by a composer's score, which indicates a sequence of notes to be performed in succession. Previous work has shown it is possible to track in real-time the musician's position in the score and detect any mistakes made (albeit with some uncertainty) [2]. We propose extending these techniques with plan-aware behavioral modeling in order to: (1) predict whether an upcoming note to be played will be performed correctly, and (2) automate diagnosis of why a given note was performed incorrectly. In the first case, if the model suggests the musician will have difficulty performing a given note, we would like to offer proactive assistance to prevent the mistake's occurrence. The success of a solution to this problem may be evaluated by comparing a musician's performance accuracy with and without the assistance enabled. In the second case, we would like to offer responsive assistance to prevent the

mistake from reoccurring. The success of a solution to this problem may be evaluated similarly.

OUR APPROACH

We have focused our initial analysis on solo piano performances. Such performance data may be readily acquired due to the commercial availability of pianos supporting real-time output of MIDI events that describe performer-piano interaction. Existing techniques may also be employed to extract similar data in real-time from ensembles of arbitrary instruments [2].

We will use a Bayesian network [3] to exploit knowledge of the user's plan (e.g. the score) in addition to (musical) context and historical observations of behavior. Bayesian Networks make it practical to perform inference under uncertainty by expressing independence assumptions between parameters. As the musician plays, any mistakes made and the musical context of those mistakes will be used to update the network's prior and conditional probabilities. We expect these probabilities and the structure of the network can incrementally gain complexity as automated learning and domain expertise influence and iteratively inform one another. Model accuracy will be evaluated using standard model validation techniques.

In order to provide the musician with ubiquitous assistance, we will ask him to read the score from an electronic display. As he performs, we will automatically generate digital annotations consistent with how the musician would manually annotate a paper copy of the score during rehearsal (Figure 1). In addition to recording specific instructions from the conductor, annotations are used to provide additional information to aid in mistake prevention for subsequent performances of the piece. In many cases, a piece being rehearsed may not be played again for a sufficiently long period of time such that a musician cannot rely on memory of the current rehearsal to assist him in the next one. It is this property, we believe, that should make the approach of automatic annotation feasible: musicians are comfortable reading annotations they do not recall making themselves so long as the annotations appear stylistically familiar. Ideally the musician should not be able to tell if he made a given annotation himself or if it was made for him.

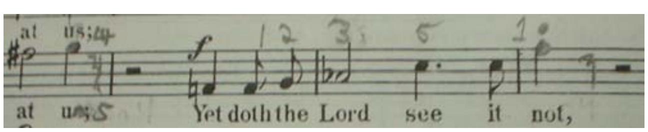

Figure 1: Annotations denoting articulation & chord structure used in a performance of Mendelssohn's Elijah

PRELIMINARY RESULTS

Our results thus far consist of analyzing existing performance data we were able to acquire from another researcher [4]. This data consists of an electronic representation of performance data and a coding of the mistakes as identified by a domain expert. The goal of our analysis was to verify the coding of mistakes and to begin classifying mistake patterns useful for modeling performer behavior. We began our analysis using the many existing tools which support interactive MIDI playback and visualization. We found piano roll notation (see Figure 2) to be particularly valuable in exploring precise details of note onsets and durations. We also wanted to complement our use of piano roll notation with a format closely resembling the familiar, traditional Western staff notation in which the original score was written. However, the abstract notion of time used by traditional staff notation can only coarsely describe the actual timing of performance events. After unsuccessfully trying to find an existing tool which addressed this mismatch, we adapted a spreadsheet program to create our own modified version of staff notation (Figure 3). As with the piano roll notation viewer, we were able to zoom in on regions of interest to better visualize precise timing of performance events. Use of these approaches has already revealed some interesting performance mistake patterns for analysis. For example, one performer tended to be late with his middle finger when playing chords with his right hand (Figure 3).

Figure 2: A musical excerpt shown in piano roll notation

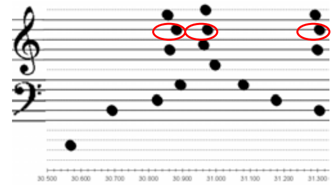

Figure 3: Modified staff notation shows precise timings in a familiar format

FUTURE WORK

In addition to the applications mentioned thus far, we would also like to investigate how plan-aware behavioral monitoring could enhance ubiquitous computing support for several other real-world scenarios: distance and self-education, fabrication and maintenance, software service monitoring, and assisting the elderly and disabled.

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